

Massachusetts Institute of Technology  
Department of Electrical Engineering and Computer Science  
6.685 Electric Machines

Problem Set 8

Issued October 22, 2013  
Due October 30, 2013

**Reminder:** We have a quiz coming up on November 6. Venue is everything through this problem set. Solutions for all problem sets up to this one will be posted over the weekend of November 2 and 3. Closed Book. One handwritten crib sheet allowed. Calculators OK but hopefully won't be needed, and likely to be a distraction.

**Problem 1:** Yet one more Induction Motor Problem.

This problem refers back to the large induction motor you considered in Problem Set 7. Go back to using the frequency independent values for rotor impedance, but consider the impact of the seventh space harmonic of stator MMF. Assume that the stator is full-pitched and has two slots per pole per phase. (NOTE: I am not suggesting that this would be a good way of making a motor!) Ignore all space harmonics other than fundamental and seventh. Also assume that  $X_2$  is attributable only to rotor slot leakage. Compute the elements of the equivalent circuit associated with the seventh space harmonic: Magnetizing and Leakage Reactances and rotor resistance. Recompute the torque speed curve. You should see an artifact in the torque speed curve that affects the torque-speed curve near  $1/7$  of synchronous speed.

**Problem 2:** DC Motor Driving a Trolley Car

In this problem we consider a 'Light Rail Vehicle' (LRV) driven by a series connected DC motor. In dynamometer tests the motor was found to develop 400 kW at 1500 RPM with a terminal voltage of 600 V. At that condition the motor was drawing 800 A. The motor has a combined field and armature inductance of 10 Hy.

The LRV weighs 40,000 kg and is geared so that it is going 25 m/s when the drive motor is turning at 1500 RPM. Traveling on level track, the car requires 75 kW to overcome drag at 25 m/S. That drag force, consisting largely of windage, can be considered to be proportional to velocity, so that drag power is proportional to the square of velocity.

1. When the trolley car is going 25 m/s on level track, how much current is the motor drawing?
2. If the operator is not paying attention and the machine is connected directly to the 600 volt line, how fast would the thing go on straight and level track?
3. What series resistance is required to limit the trolley car to a top speed of 25 m/S? At that speed, how much power is being dissipated in the dropping resistor?
4. If current into the motor is limited to 2,000 A, how steep a grade can the trolley car climb? If voltage is limited to 600 V, how fast can it climb that grade? (For the purpose of this part of the problem, ignore friction and windage drag: consider only the grade).

5. Suppose the trolley car is at rest but about to go up a 4 degree grade. (The brake is on). The brake is removed just as voltage is applied to the motor. Simulate the acceleration transient under two conditions:

- The supply is a stiff 600 V.
- The supply is 600 V but with a current limit of 2000 A.

Note: you will probably want to use something like Matlab's ODE23() to do the heavy lifting for this problem.

**Problem 4: Dynamo**

A DC generator has the following characteristics:

Field Resistance	$R_f$	249 $\Omega$
Armature Resistance	$R_a$	1 $\Omega$
Field Inductance	$L_f$	10 Hy
Number of Field Turns		1000

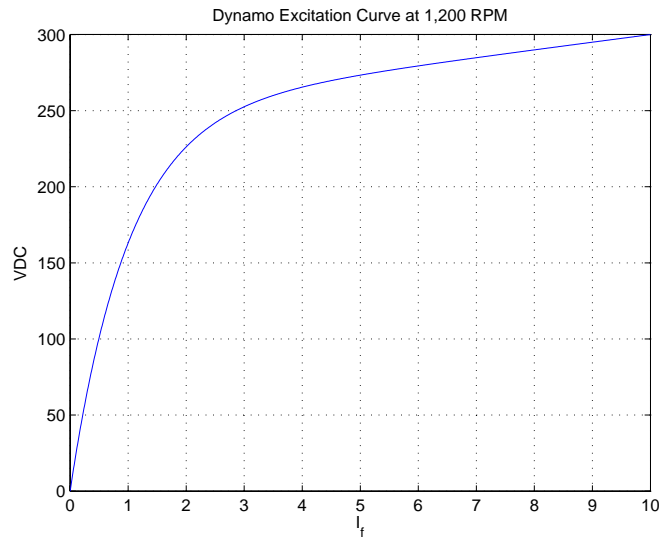


Figure 1: DC Generator Test Curve at 500 RPM

Operating at a speed of 500 RPM, the machine exhibits the saturation curve shown in Figure 1. A very good approximation to the excitation characteristic, which is open circuit voltage plotted against field current, is:

$$E_{af} = 5I_f + 250 \left( 1 - e^{-\frac{I_f}{I_{f0}}} \right)$$

where  $I_{f0} = 1$  A.

The machine is set up to be a dynamo (a self-excited generator), with the field winding connected directly to the terminals of the armature. Characteristics of the machine are:

- Above what speed will this machine self-excite?
- Operating at 750 RPM, what is the steady state voltage if the machine is otherwise unloaded?
- For a range of rotation speed from the minimum speed for self-excitation to 1,000 RPM, estimate and plot the terminal voltage, assuming the machine is not otherwise loaded. *HINT:* This is an excellent application for MATLAB's `fzero` function or the equivalent nonlinear equation solvers of other mathematical assistants.
- Calculate the output voltage as a function of load current, with the machine turning at a steady 750 RPM.
- Now, the machine is to be compounded by use of a series field winding to make it a 'stiffer' voltage source. To estimate how many turns should there be to make it 'flat' compounded (Zero apparent output impedance), calculate the derivative of internal voltage with field current, and give the series field enough turns to make the increase in internal voltage with load current match the decrease in terminal current because of armature resistance. Plot the output voltage with the uncompounded machine and with the compounded machine for load currents from zero to 25 A.
- Without this series (compound) field, the machine is operating at 750 RPM when the field winding is suddenly connected to the armature terminals. We expect it to self-excite. Simulate this buildup, plotting voltage as a function of time. Assume the field current starts at 0.1 A.

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